A course in low vision practice

PART 5 – Magnification and magnifiers

Barbara Ryan and **Tom Margrain** define magnification and describe some of the ways various optical appliances achieve it (CET Module C2996)

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Association of Optometrists Ireland

MAGNIFICATION increases the retinal image size. For people with a visual impairment this makes an object easier to see because although the retinal image size increases, the area of visual loss remains the same size (Figure 1).

There are four ways of creating magnification:

- Increase the size of the object
- Decrease the viewing distance
- Transverse magnification
- Telescopic magnification.

FIGURE 1. Magnification increases the size of the retinal image but the area of visual loss remains the same size

INCREASING THE SIZE OF THE OBJECT

Also known as relative size magnification. This is a linear relationship: making the object twice the size makes the image on the retina twice as large, hence creates X2 magnification (Figure 2).

$$M = \frac{h_2}{h_1} = \frac{\text{new object size}}{\text{old object size}}$$

Examples of this type of magnification are large print books or watches (Figure 3). Many other examples are given in a future article. This form of magnification is usually limited to about 2.5X because of the physical limitations of how big you can make an object such as a book.

DECREASING THE WORKING DISTANCE

Also called relative distance magnification. This, too, is a linear relationship: half the distance of the object and the retinal image becomes twice as large and hence creates X2 magnification (Figure 4).

$$M = \frac{\text{old object distance}}{\text{new object distance}}$$

For example, viewing the television from 3m rather than 6m gives X2 magnification (Figure 5).

This type of magnification can be used at near too, for example bringing the print closer to the eye from 40cm to 10cm gives X4 magnification. Many children and young adults use accommodation to provide this form of magnification, mainly for short duration near tasks. Myopes, who take off their glasses and hold the object closer, can often achieve magnification without the need for accommodation. For older adults who do not have enough accommodation, or younger people who cannot sustain the accommodative demand, the image on the retina of the closer object will be magnified but blurred.

Plus lens magnification

A plus lens, placed so that the object is at the anterior focal point of the lens, allows a near object to be focused clearly on the retina and accommodation to be relaxed. Most hand and stand magnifiers work on this very simple principle.

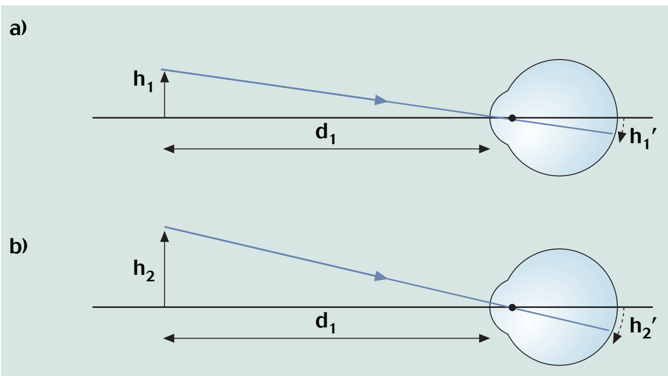

FIGURE 2. Relative size magnification (a) an unmagnified object (h_1) forms an image h_1' on the retina; (b) a larger object (h_2) (the same distance from the eye) forms a larger image h_2' on the retina

A COURSE IN LOW VISION PRACTICE

In this series of 12 articles, Barbara Ryan and Tom Margrain from the School of Optometry and Vision Sciences, Cardiff University outline some of the basic theory required for low vision practice. These articles are based on modules which were developed to train the optometrists and dispensing opticians who provide The Welsh Low Vision Service which has been developed and is funded by the Welsh Assembly Government

Although the distance between the magnifier and object needs to be kept constant at the focal length of the lens, so the rays emerging from the lens will be parallel, the distance between the magnifier and eye can be increased without any change to the magnification occurring (Figure 6).

So, you can have the plus lens close to the eye, for example in a spectacle lens, or remote from it, for example in a hand magnifier or stand magnifier.

The plus lens creates the magnification by allowing the patient to adopt a closer viewing distance:

$$M = \frac{\text{old object distance}}{\text{new object distance}}$$

FIGURE 3. Making things bigger, such as number dials, creates relative size magnification

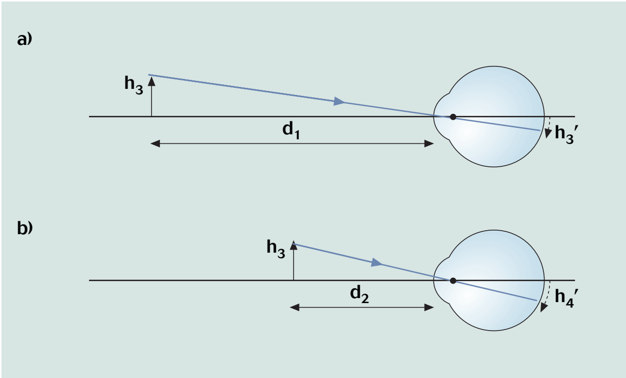

FIGURE 4. Relative distance magnification (a) an unmagnified object h_3, at a distance d1 from the eye, forms an image h_3' on the retina. (b) The same object h3 viewed at a closer distance (d_2) from the eye forms a larger image on the retina (h_4')

FIGURE 5. Sitting closer to the TV creates relative distance magnification

Traditionally it is assumed that objects were held at 25cm (ie the old object distance) using 4.00DS accommodation or a +4.00DS reading addition.

$$M = \frac{\text{focal length of } +4.00\text{DS}}{\text{focal length of the magnifying lens}}$$

$$M = \frac{0.25}{1/F} = \frac{F}{4}$$

In real life, however, few people habitually hold things at 25cm, or have a +4.00D addition. Labelling of low vision aids using dioptric power only would allow a unique formula for each patient to be devised. For example, if a person habitually read at 50cm with a +2.00DS addition:

$$M = \frac{\text{focal length of } +2.00\text{DS}}{\text{focal length of the magnifying lens}}$$

$$M = \frac{0.50}{1/F} = \frac{F}{2}$$

Therefore, you could determine how much larger the retinal image actually was compared to the person's habitual reading situation.

Most lenses used in low vision aids are thick so the equivalent power (Fe) of the lens, rather than front or back surface power should be used:

$$M = \frac{Fe}{4}$$

You cannot just measure the equivalent power on a focimeter (like the front or back surface power). Unfortunately, few manufacturers provide this information and methods to measure it are protracted.

Limitations of plus lens magnifiers

◆ *Short working distances*. Although you can vary the distance from the eye to the magnifier, the distance from the magnifier to the object is often very short. This type of magnifier is available up to +80.00 DS but the working distance is 1.25cm! The short working distance makes it hard to get enough light to the object and the working distance may be too short for some tasks such as knitting.

◆ *Small depth of field*. Moving the object away from the focal point of a magnifying lens changes the vergence of the rays entering the eye and hence causes the image on the retina to become blurred. The amount you can move the lens without the patient noticing a difference is the depth of field. Although a person's pupil size and ability to detect blur affects the depth of field, it is very small for higher powered plus lenses which is why most low vision aids over 20.00DS are mounted in stands.

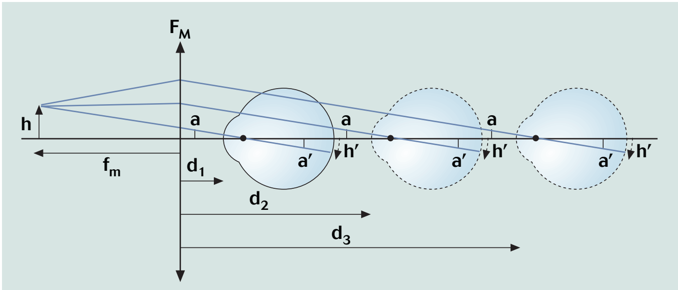

FIGURE 6. If a plus lens magnifier (F_M) is held so that the object (h) is positioned at the anterior focal length (f_m) of the lens changing the separation between the eye and lens (d_1, d_2 and d_3) will not change the retinal image size (h′)

Field of view of plus lens magnifiers

For plus lens magnifiers:

The field of view, $y = \frac{D}{dF_e}$

Where **D** is the diameter of the lens, **d** is the distance of the magnifier from the cornea and F_e is the equivalent power of the magnifier.

In magnifiers, as the power of the lens increases, the diameter of the lens gets smaller due to physical constraints in manufacturing them and weight. As can be seen from the equation, this compounds the problem of reduction of field of view with increasing magnification. This is why patients often ask for larger magnifiers. However, the parameter that actually has the greatest effect on the field of view is the eye to magnifier distance.

Therefore, to maximise the field of view, the patient should be encouraged to hold the magnifier as close to the eye as possible, a spectacle-mounted plus lens giving the best field of view of all.

Using reading adds and accommodation with plus lens magnifiers

In reality, most people do not intuitively wear their distance spectacles and relax all their accommodation when using a plus lens magnifier. It is natural for pre-presbyopes to converge and accommodate for the physically near location of the object and for presbyopes to expect to wear their near correction for reading. When this happens, in order for the retinal image to be clear, the plus lens magnifier needs to be positioned closer to the object than the anterior focal length of the lens so that the emergent rays are divergent. The reading addition or accommodation then converges the divergent rays to parallel (Figure 7). Holding the magnifier in this way increases the field of view.

Whether the person uses accommodation or a near addition, the magnifying system is no longer a simple plus lens magnifier, but a plus lens combined with accommodation or reading addition separated from each other (Figure 8).

The magnification produced by this combined system depends on its equivalent power:

$$M = \frac{Fe}{4}$$

Where the equivalent power of the combined system is:

$$F_e = F_M + F_A - (z F_M F_A)$$

Where F_M is the magnifer power, F_A is the power of the accommodation or reading

▶

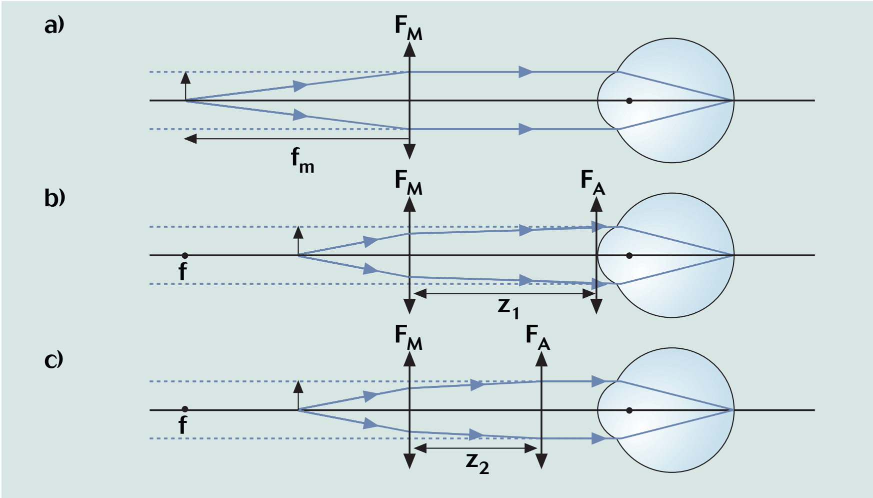

FIGURE 7. When the object is placed (a) at the focal point (f) of the magnifier (F_M) the emergent rays are parallel and no accommodation or near addition is required to focus the image clearly on the retina. When the object is placed closer to the magnifier (F_M) than the anterior focal point (f) (Figures 7b and 7c), divergent light leaves the magnifying lens and either (b) accommodation (F_A at corneal vertex) or (c) a reading addition (F_A) is required to produce a clear retinal image

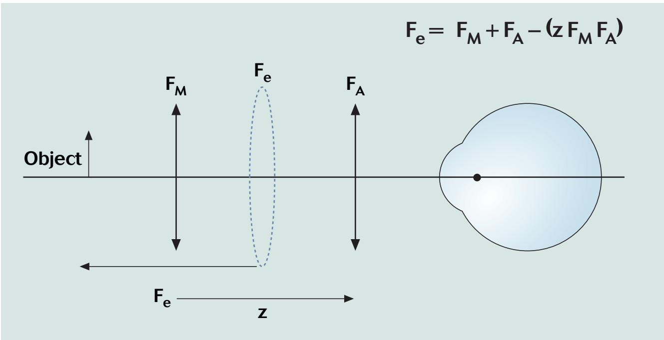

FIGURE 8. Representation of the single equivalent lens (F_e) of a multi-lens system incorporating a magnifier (F_M) and a spectacle near addition (F_A) separated by a distance z

addition and **z** is the separation (in m) between the magnifier and the eye if the person is accommodating. Or the separation between the magnifier and the spectacle lens if the person is wearing a near addition.

As previously stated, if a plus lens magnifier is held at the focal point of the lens, without the use of accommodation or near addition, the distance from the eye to magnifier doesn't affect the magnification (although the field of view will change). However, if the person accommodates or uses a near addition, so that the lens is held closer to the object, then the separation between the magnifier and the eye can have an enormous effect on the magnification. Figure 9 shows that the higher the power of the magnifying lens the greater the effect this separation has on the magnification.

Trade magnification

As stated, traditionally: $M = \frac{Fe}{4}$

This is derived by comparing the viewing distance that a plus lens magnifier achieves with that of a +4.00DS near addition or 4.00DS accommodation. It has been argued that the +4.00DS near addition or accommodation should be compared to the effect of the magnifier with the +4.00DS near add or accommodation (ie $F_e = F_M + 4$).

Therefore:

$$M = \frac{F_M + 4}{4} = \frac{F_M + 1}{4}$$

This 'trade magnification' is sometimes used by manufacturers when labelling their magnifiers but it is of little use in practice.

Stand magnifiers

Stand magnifiers allow the maintenance of a precise magnifier to object distance which is advantageous because of the small depth of focus of plus lens magnifiers. However, most fixed stand magnifiers are positioned so that the lens to object distance is less than the anterior focal length of the lens. This reduces aberration of the image. It also means that the rays of light leaving the lens are divergent and the patient has to accommodate or wear a near addition to neutralise the divergence so that parallel light enters the eye (Figure 10). Magnification with a stand magnifier is therefore not constant but varies with the separation between the eye/or spectacle plane and the magnifier as described previously.

Added difficulties with stand magnifiers result because the distance the lenses are fixed from the object is not marked on the device and this distance varies between magnifiers and within a particular range of magnifiers. The near addition or accommodation that is required with each stand is therefore different and not often apparent. In general:

- The lower the power of the stand magnifier the more divergent the emerging rays and the higher the reading addition required
- The higher powered stand magnifiers (>28.00DS) are often set very close to the anterior focal point so that the emergent rays are almost parallel and so no accommodation or near addition will be required
- Most COIL devices are set at a unified vergence of -4.00 DS
- Most Eschenbach devices state a working distance for a given addition.

All this poses a problem when prescribing stand magnifiers for presbyopes. In theory you would need to prescribe a unique pair of spectacles for each stand magnifier. In practice, however, you want to keep the prescribing of spectacles for people with low vision to a minimum because their vision is likely to change.

Spectacle-mounted plus lens magnifiers

Mounting magnifiers in spectacles is the best solution optically to the difficulties encountered with plus lens magnifiers: they give the best magnification and ▶

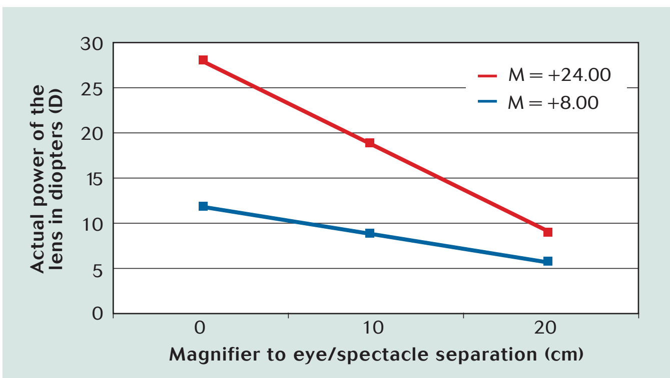

FIGURE 9. The power of two magnifiers (used with +4D accomodation/near addition) when used at different distances from the eye/ spectacle plane

greatest field of view for the lowest dioptric power of lens. However, the majority of patients do not like anything that focuses less than 25cm from the spectacle plane. Younger people seem to accept shorter working distances better than older people.

Stand and hand magnifiers don't allow binocular viewing except in very low powers. Spectacle mounted low vision aids can be prescribed monocularly or binocularly if prisms are incorporated to help convergence (1Δ Base in per 1.00DS over +4.00DS). Over +10.00DS the person is unlikely to be binocular.

Single-vision conventional meniscus, aspheric or lenticular lenses can be used and are available up to +20.00DS with a cylindrical correction. Special low vision lens designs are available such as hyperoculars which are bi-convex aspherics but these are not available with a cylindrical correction. Ready glazed half eyes or clip-ons are available and are useful for trials to save costly mistakes. (Figure 11)

The range of high addition bifocal lenses has dramatically decreased in the last few years. At the time of writing Sola do up to +16.00DS addition in a 25mm round seg and Norville up to +8.00DS addition in 25mm or 35mm flat-top segs. Using a Franklin Split design almost any addition can be made in theory but in practice cosmesis will limit the power greatly.

Practical considerations when prescribing plus lens magnifiers

◆ If you are prescribing a hand magnifier, an older person should be encouraged to use their distance spectacles and try to focus the object at the focal point of the lens. This will give greatest flexibility of use because it doesn't matter how far from the eye the lens is held, the magnification is unaffected (although the field of view is)

◆ With hand or stand magnifiers, if a patient complains about the small field of view, show them how it improves if they bring it closer to their eye

◆ If you are prescribing a hand or stand magnifier and the person is accommodating or using their near addition, encourage them to use it as close to the eye or spectacle plane as possible. If they find this difficult/impossible a higher powered magnifier may be required to achieve the required magnification

◆ For young people, who usually accommodate when using near low vision aids, spectacle-mounted plus lenses are often tolerated well because they give the best magnification and field of view and allow their hands to be free

◆ When you prescribe a low vision aid, particularly a stand magnifier, you need to think about the spectacles the person should use with them (eg distance/near; +2.50 Add/ +4.00 Add)

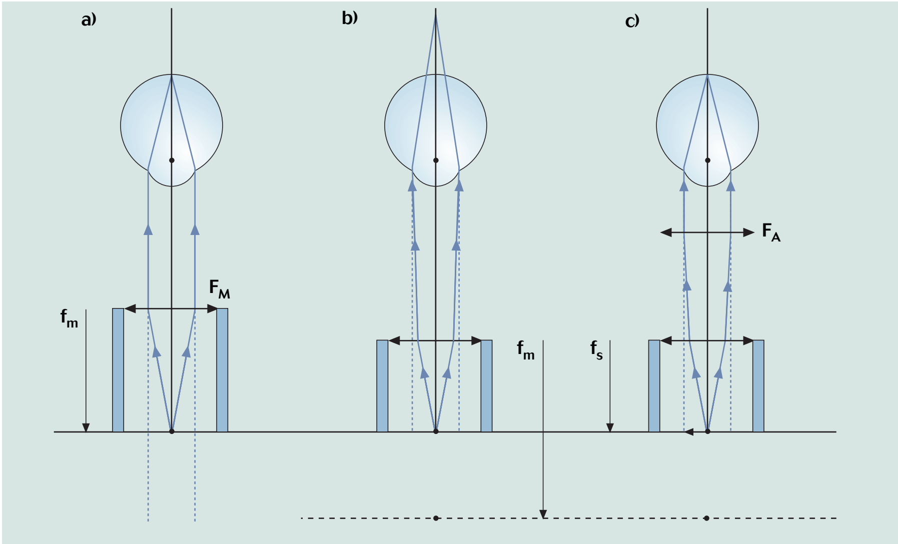

FIGURE 10. If a stand is fixed so that the object is at the anterior focal length (f_m) of the magnifying lens (F_M) (a) emergent rays are parallel and will be focused on the retina. (b) Most stands are fixed so that the distance from the object to the magnifier (f_s) is less than the anterior focal length of the lens (f_m) the light entering the eye will be divergent and the retinal image blurred unless (c) a reading addition (F_A) (or accommodation) is incorporated into the system so that parallel light enters the eye

FIGURE 11. Ready glazed half eyes

◆ The design of the spectacle lens is important. If the near Rx is a bifocal or varifocal they will be looking through the distance portion if they are holding the magnifier at the spectacle plane.

TRANSVERSE MAGNIFICATION

This is also known as 'real image magnification'. Optical magnifying systems are limited to magnification of about X20. Transverse magnification produced electronically is available in much larger magnifications of X50 and over.

CCTVs

Closed circuit televisions (CCTVs) produce real image magnification electronically using a camera to create a magnified image on a monitor screen. They are usually used for near or intermediate tasks but there are some with cameras that can be pointed at distant objects.

The magnification of a CCTV is the direct increase in size of an object to the screen image:

$$M = \frac{\text{Linear size of image on the screen}}{\text{Linear size of original object}}$$

In theory, CCTVs should be the solution to all the frustrations of low vision aid users. As well as producing much higher amounts of magnification and improving the contrast of the image they do not suffer as much, or at all, from the problems of lens magnifying systems, that is small field of view, short working distances and aberrations. In practice, however, they are expensive, quite difficult to use and very bulky (see page 31). Only a small proportion of the low vision population use CCTVS and most do so mainly for longer, sustained reading tasks in conjunction with optical low vision aids for short, survival tasks.

Types of CCTV

The most common type of CCTV is a TV screen mounted above an 'X-Y' table (where the object is placed or held over).The table allows you to move the object horizontally or vertically. Knobs on the front panel allow you to change the magnification, adjust the focus and reverse the contrast. Some models have additional features, for example, many modern CCTVs can use VDU monitors as output so that you can link the magnified images with text enhancement software. Standard CCTVs cost about £1,500 but many models cost much more. A range of video magnifiers is now available (Figure 12).

TV readers are much cheaper (£250 to £500). They consist of a hand-held camera which is plugged into the patient's own television (Figure 13). The magnification is limited, often fixed at one value and dependant on the size of the television screen. Most give the option of reverse polarity and some have a stand the camera can be mounted on to allow a pen

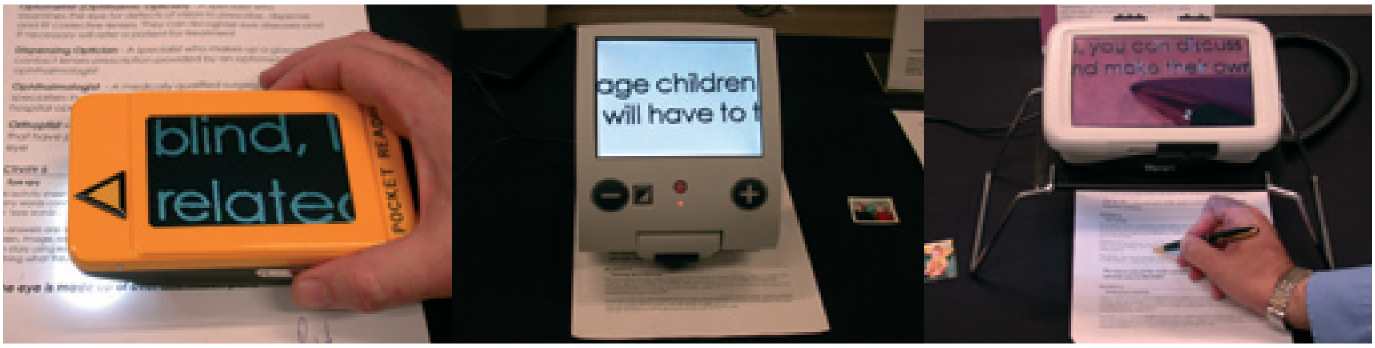

FIGURE 12. Video magnifiers are now widely available

underneath. Although cheap and quite portable they are difficult to manipulate (see page 32).

In recent years, a number of head-mounted CCTVs have been developed, such as the Jordy. The camera and TV screens are mounted in a virtual reality-type headset and the control box is attached to your belt. These haven't really caught on because they remain very expensive, heavy, difficult to use, cosmetically poor and as yet cannot be used when walking around.

Getting hold of CCTVs

CCTVs are not provided on the NHS, although employment and education services usually will provide them (or in the case of a person in employment give an 80 per cent grant towards their cost) if deemed necessary for the person's work or schooling. Older people who want them usually have to buy them themselves. Many public libraries, some voluntary organisations for the blind and some social services departments have them so that the person can try them. Most companies will let people try the CCTV in their own home for a short period before purchase. Due to the great expense and difficulty using CCTVs this approach should be strongly recommended to patients.

Bar and flat field magnifiers

Although very different to CCTVs, these are also real image magnifiers. They are single lenses of hemi-cylindrical or hemispherical form which are designed to be put flat onto the object (usually text). Although they are plus lenses the magnification is produced by lateral magnification of the object rather than a change in viewing distance. The thicker the magnifier is in relation to its radius of curvature, the higher its magnification. This is unlikely to exceed X3 as a maximum because of the size and weight although they can be used in conjunction with spectacle mounted systems or accommodation to increase the magnification while keeping a reasonable working distance.

The image formed is very close to the object, so a change in viewing distance has little effect on the magnification and the field of view also does not change with the viewing distance but with the diameter of the lens. This means a more normal posture can be adopted. The lenses do not suffer from aberrations and their light-gathering properties mean that the area within the lens has a higher illumination than the surround.

FIGURE 13. A TV reader

Flat field magnifiers are very useful for children with a visual impairment. They can be placed on a text book on a desk, used with accommodation and or spectacle mounted LVAs, don't need an extra light source and look like a paper weight or 'crystal ball'.

TELESCOPIC MAGNIFICATION

Also known as angular magnification. Telescopes are the only optical aid for distance magnification, but can also increase working distance when focused on a near target. They are a very effective way of producing magnification while allowing the person to stay at their chosen distance from a task, such as viewing a street sign or blackboard. However, they suffer from restricted fields of view and you can't walk around while using one because of the distortion of space and movement perception. Their use requires quite a lot of manual dexterity, skill and practice, particularly to follow moving objects. For this reason, distance telescopes are often prescribed at a follow-up appointment because this allows ability and motivation to be assessed more fully. Only a very small proportion of people with low vision use them (the more adaptable). Two types of telescope are used in low vision work: Keplerian (Astronomical/terrestrial) and Galilean.

Keplerian telescopes

A convex objective lens is separated from a convex eye-piece lens. Parallel rays of light from a distant object are focused by the objective lens at the anterior focal point of the eye-piece, from which the rays emerge parallel (Figure 14). In this form they are called astronomical telescopes. The image is inverted which is obviously not suitable for low vision work so an erecting prism is incorporated. When this is done, the telescope can be called terrestrial.

Galilean telescopes

A convex objective lens is separated from a negative eye-piece lens. The first focal point of the eye-piece lens is co-incident with the second focal point of the objective lens. Parallel rays of light from a distant object are converged by the objective lens

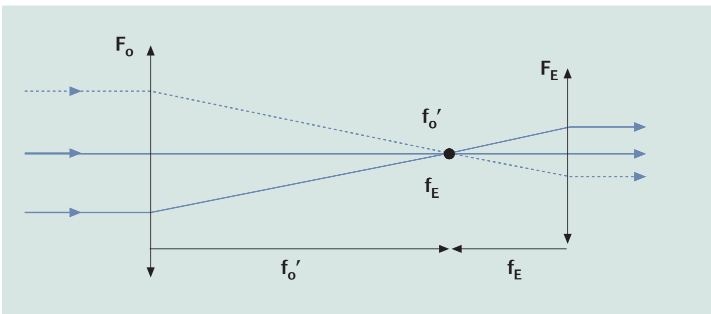

FIGURE 14. A schematic representation of a Keplerian telescope with a positive objective lens (F_0) and positive eye piece (F_E). Parallel rays are focused at the anterior focal point o fthe eye piece and emerge parallel. The top dashed ray of the entrance bundle becomes the bottom ray of the exit bundle so the image is inverted. Note the reduced field

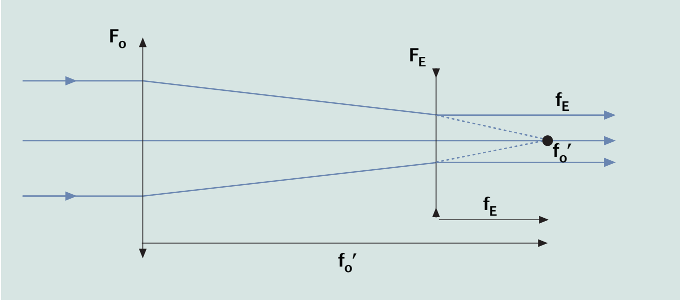

FIGURE 15. Representation of a Galilean telescope with a positive objective lens (F_0) and negative eye piece (F_E). Parallel rays are converged by the objective lens and intercepted by the eye piece before they focus and emerge parallel. The rays do not cross and the image is erect. Note the reduced field

and are intercepted before focusing by the eye-piece lens and emerge parallel from the system (Figure 15.) The image is erect.

Production of angular magnification

The magnification produced by telescopes is called angular magnification because they magnify by increasing the angle made by the rays with the optical axis after passing through the telescope.

$$M = \frac{\text{angle subtended at eye by the image}}{\text{angle subtended at eye by the object}}$$

Comparison between telescopes

Keplerian telescopes are longer, heavier, and more expensive than Galilean systems of equivalent magnification. The image quality is much poorer with a Galilean telescope than a Keplerian system and hence is only available in low magnifications (up to about X3) while the Keplerian is available in much higher magnifications.

◆ *Barbara Ryan and Tom Margrain work at the School of Optometry and Vision Sciences, Cardiff University*

MULTIPLE-CHOICE QUESTIONS

1 Which statement is false?
A Making an object twice as large creates X2 magnification
B Halving the distance between the eye and object creates X4 magnification
C Relative size magnification is limited to about X2.5
D Bringing print closer to the eye from 40cms to 10cms creates X4 magnification

2 Which statement is correct?
A If a person wears their reading glasses and uses a hand magnifier the magnification is the same no matter what distance from eye magnifier is held
B If the distance between a hand magnifier and the object is kept constant and the person wears their reading glasses, the distance between the eye and magnifier can be increased without any change in magnification occurring
C If the distance between a magnifier and the object is kept constant at the anterior focal length of the hand magnifier and the person wears their distance spectacles and relaxes accommodation the distance between the eye and magnifier can change without any change in magnification
D If the distance between the magnifier and object is kept constant at the anterior focal length of the lens and the person wears their distance spectacles and relaxes accommodation, as the distance between the eye and magnifier increases the magnification decreases

3 What is the trade magnification of a +20.00DS hand magnifier?
A X4
B X5
C X6
D X6.5

4 If you prescribe high addition spectacles to keep the person binocular you need to incorporate?
A 1Δ base-out for each + 1.00DS over +4.00DS
B 1Δ base-in for every + 4.00DS over +1.00DS
C 1Δ base-out for every + 4.00DS over +1.00DS
D 1Δ base-in for every + 1.00DS over +4.00DS

5 Transverse magnification is available up to about?
A X10
B X20
C X40
D X50 or more

6 Which of the following statements about TV readers is false?
A They are as expensive as projector-screen CCTV systems
B The image size is dependent on the TV
C The image quality is dependent on the TV
D They are not adaptable to reverse contrast

7 Which statement is false about Keplerian telescopes?
A Keplerian telescopes have convex eye piece and objective lenses
B A prism is needed to invert the image
C They are shorter than Galilean telescopes
D They are available up to about X20

8 Which statement is false about Galilean telescopes?
A They have a concave objective lens and concave eye piece lens
B The image they create is erect so no prism is needed
C They are only available for distance viewing in low magnifications up to about X3
D They are cheaper than Keplerian telescopes of equivalent magnification

9 Which of the following is not true for flat field magnifiers?
A They are easily portable
B They have good light gathering properties
C They are popular with children who can use accommodation to supplement the low power of the aid
D They are available in a wide range of magnifications

10 Which of the following exploits relative distance magnification?
A Telescopes
B Large print books
C Spectacle magnifiers
D Colour and shape-coded buttons

11 Which of the following exploits angular magnification?
A Telescopes
B Large print books
C Spectacle magnifiers
D Colour and shape-coded buttons

12 Which of the following exploits relative size magnification?
A Telescopes
B Large print books
C Spectacle magnifiers
D Colour and shape-coded buttons

The deadline for responses is Thursday, February 16

Module C2296 To take part in this module go to www.opticianonline.net and click on the Continuing Education section. Successful participation in each module of this series counts as two credits towards the GOC CET scheme administered by Vantage and one towards the Association of Optometrists Ireland's scheme.